Longwall Tailgates: The Technology for Roof Support has Improved But Optimization is Still Not There

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ABSTRACT

Roof support technology for longwall tailgates has changed dramatically during the past decade. Filling tailgates with conventional wood cribs is becoming the exception rather than the rule. Modern engineered timber support systems and a host of other alternative support products provide far greater capacity as well as stiffer response, thereby allowing the supports to resist roof movement with much less displacement than the soft wood cribbing used in the past. For these reasons, these products can provide superior roof control. In addition, the material handling requirements for support installation have now become a major consideration in the support design and selection process. Products such as conventional wood cribbing that require piece-meal construction of bulky, heavy components have diminished, while prop-type supports and products that can be installed with machinery and pumpable support technologies have grown in use resulting in fewer injuries to mine workers. Now, the opportunity exists to provide the safest, most cost effective support system, through engineering design rather than by trial and error and to optimize the use of the support system chosen. Yet this is rarely done. The key to accomplishing this task is to understand the interaction of the support system with the ground conditions at the installation site. A major focus of the paper is to conceptualize the support and interaction through the use of a ground reaction curve which relates the support resistance to the convergence of the longwall tailgate. The goal of any roof support design is to control the ground deformations and maintain the structural integrity of damaged or broken ground to the extent possible to provide a stable mine opening. In general, deformations will be a function of the stress environment and inherent strength of the surrounding rock mass. However, if the deformations are intimately linked to the stress changes such that the deformation can be controlled by the load resistance or reinforcement provided by a roof support system, then the loading behavior can be described as load-controlled. Conversely, if the deformation occurs irrespective of the installed support (assuming practical limitations), then the loading behavior is described as displacement-controlled. In this case, the deformation can be considered irresistible from a practical standpoint. In this context, the nature of the loading has significant consequences on the support design requirements. Finally, examples using the NIOSH Support Technology Optimization Program (STOP) to develop design criteria using ground reaction data from underground studies and ways to include uncontrolled convergence as part of the design criteria for standing roof supports will also be discussed.

Introduction

In general, longwall mining, as with most mining operations, has benefited from years of experience and, to a large extent, on trial and error practices whereby insight into what works and what doesn't has been learned from past practice. Through this approach, engineering requirements eventually migrate to a satisfactory design with an acceptable level of risk. However, optimization is rarely achieved through this design process.

Longwall roof support design is no exception and mostly continues to be a product of this philosophy. Major falls in longwall gateroads have become more and more uncommon as pillar design practices have improved largely through empirical design practices, such as that employed in the ALPS program, but problematic tailgate behavior is still a major concern of many longwall operators (1). Assuming the pillar system is properly designed, then control of the gateroad is usually dependent on the primary and secondary support system.

Despite widespread developments in new support technologies, the design of both primary and secondary support for longwall gateroads remains uncertain and often controversial. The key to optimizing roof support design, both primary and secondary, relies on an understanding of the strata mechanics and the interaction of the support with the strata. The ultimate goal is to match the support design to the strata mechanics to optimize the control provided by the support system.

This paper will focus on secondary support design, particularly standing support systems, for longwall tailgates. The latest support developments applicable to longwall tailgates will be presented, but the primary objective of the paper will be to discuss the strata mechanics and ways in which the support and strata interaction can be evaluated to provide an optimized support design. In order to do this, it is necessary to understand the strata behavior and to determine what the support can and cannot control relative to the strata activity. Too often the tendency in roof support design is a "bigger the better" approach. Trying to resist strata activity that is irresistible is generally counterproductive to support optimization and often to roof control. This must be fully understood in the selection of standing passive roof support systems that to a large extent react to roof behavior rather than control it. Hence, an optimized support design is one that balances its reaction to ground forces that it can and cannot control, and this is also the reason why there is no single support that can be the most effective in all conditions.

Strata Mechanics for Longwall Mining

In order to optimize the design of a support system, the loading characteristics of the support must be matched to the behavior of the strata in which the support system is to be employed. Obviously, this requires insight into the strata mechanics. Although strata mechanics associated with longwall mining is a complex system, understanding a few basic concepts will help to clarify the support design requirements.

In any underground mining activity, the in situ vertical and horizontal stresses that exist in the rock are disrupted and redistributed by the mining process. The most fundamental concept pertaining to any underground operation is that the ground will tend to move away from areas of high stress and toward areas of low stress, much like air or water will flow from an area of high pressure to an area of low pressure. In simplistic terms, whenever an opening in the ground is created, the loss of confinement creates an area of "low stress" to which the ground will move towards. Hence, the ground will naturally want to try to close an opening such as a longwall gateroad, and will do so until the stress has been sufficiently redistributed to the surrounding strata and remaining coal structures. In longwall mining, the formation of the gob area also creates a void or an area of stress relief toward which the strata will move causing horizontal displacements of the ground (figure 1). It is also important to realize that these movements are not uniform among the different layers of strata, and can cause rotation of the stress field that may contribute to shearing along interfaces or bedding planes between individual layers of strata.

Horizontal movement of strata can also be attributed to the Poisson effect due to increases in vertical stress from abutment loading and other stress redistribution causing lateral dilation of the bedded layers in differing degrees due to the differences in material properties of the individual strata layers.

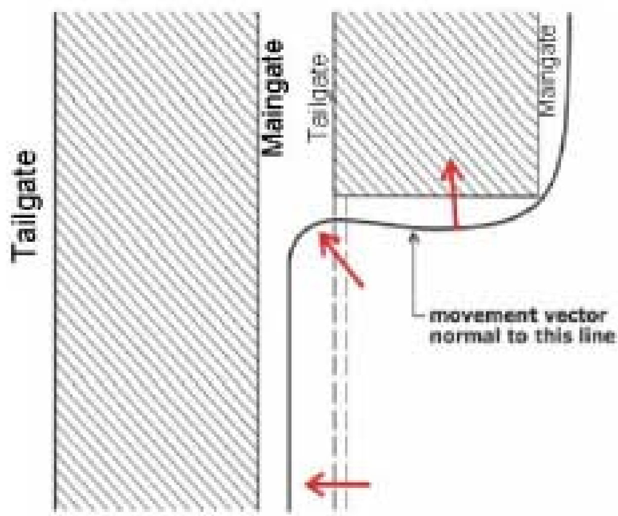

Figure 1. Horizontal displacements of ground associated with gob formation in longwall mining. (Courtesy of SCT Operations, Australia.

Another important point to remember is that stress cannot be transferred efficiently through broken ground, resulting in stress concentrations at the boundaries of damaged rock within the roof strata that can cause additional damage to the roof structure. When an opening is created, the immediate strata above the opening tends to soften with the creation of a pressure arch around the opening. This softened ground tends to disrupt the general movement of the roof towards the gob areas, resulting in a localized area of compression in the immediate roof which causes it to deform downward into the mine entry and often causes additional damage to the immediate roof beam. Numerical modeling conducted by SCT Operations in Australia indicates that the magnitude of horizontal movement on one side of the roadway is greater than on the other side (2). According to Tarrant, the stress redistribution associated with the formation of the gob causes an abutment stress on the gob side of the roadway. Following our basic premise that strata moves away from areas of high stress, the immediate roof then moves horizontally from the gob side toward the entry opening which is opposite the general movement of the strata towards the mined out gob. Essentially, the high stress acts like a speed bump for the strata layers heading toward the gob. Tarrant describes it this way, "The differential movement within an individual layer is like a car speeding along the freeway, piling into a slower moving car in the front, and suggests that this activity can be classified as displacement-controlled behavior." Figure 2 illustrates a common mode of roof failure resulting from horizontal movement of strata within the immediate roof.

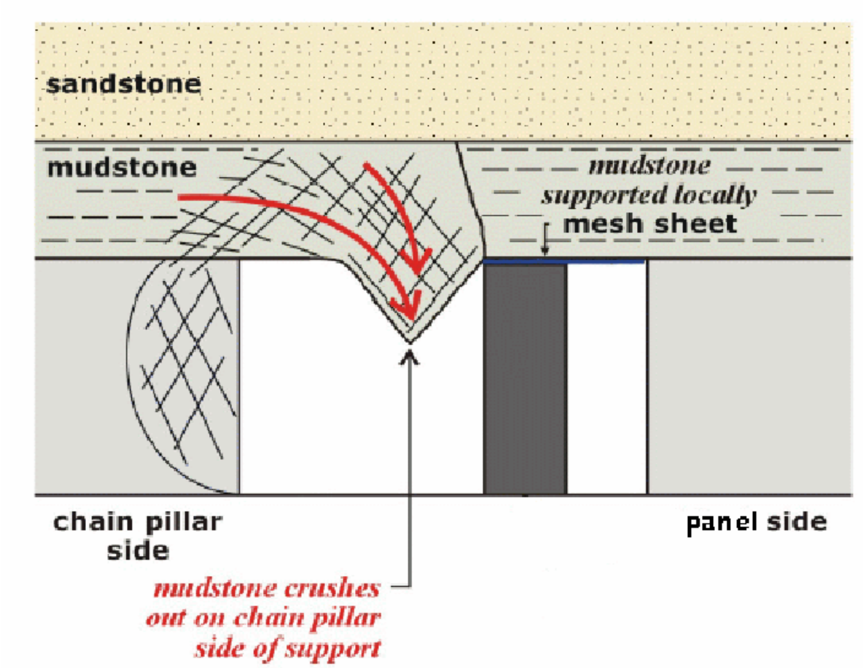

Figure 2. Common failure mode where immediate roof is moving laterally under asymmetrical stress condition (Courtesy of SCT Operations, Australia).

Controlling strata deformations due to horizontal stresses is significantly more difficult for standing roof supports, if for no other reason than the support resistance is not acting in the same orientation as the stress field and strata deformations. Simply put, the support is vertical and source of the stress and resulting ground movement is horizontal. So how can shear forces along bedding planes be prevented or at least controlled? Roof bolts do provide direct resistance to these shear forces, but can standing supports contribute? Since the standing supports as they are loaded provide a vertical (clamping type) force to the immediate roof beam, in theory, this force can increase the shear resistance along bedding planes. This then brings up another controversial issue, that of pre-tensioning bolts or in the case of standing supports, preloading or active loading capability. In theory, this can provide some degree of control over these horizontal stress regimes, but again the question becomes how much load is necessary and what area of influence do the support systems have over the rock mass? While these issues are relevant to the subject of support and strata interaction, they are beyond the scope of this paper.

In general, strata activity can be broken down into two major categories: (1) global activity and (2) local activity. Global activity occurs at the scale of the longwall and involves the larger forces associated with the redistribution of stress in the overburden rock masses during the longwall extraction. Local strata activity occurs on the scale of the gateroad, involving primarily the immediate roof and perhaps the immediate floor of the mine entry. This classification of strata activity encompasses the most fundamental aspect of standing roof support design; that is determining what strata behavior the support can and cannot control. The next section further defines this basic strata behavior as load-controlled and displacement-controlled strata activity.

Understanding the Difference Between Displacement-Controlled and Load-Controlled Strata Activity Relative To Support Design

The goal of any roof support design is to control the ground deformations and maintain the structural integrity of damaged or broken ground to provide a stable mine opening. In general, deformations will be a function of the stress environment and inherent strength of the surrounding rock mass. However, if the deformations are intimately linked to the stress changes such that the deformation can be controlled by the load resistance or reinforcement provided by a roof support system, then the loading behavior can be described as load-controlled. Conversely, if the deformation occurs irrespective of the installed support, then the loading behavior is described as displacement-controlled. In this case, the deformation can be considered irresistible from a practical standpoint. In this context, the nature of the loading has significant consequences on the support design requirements.

The Classic Roof Control Mechanism

The following roof control mechanism is typically assumed (see figure 3). A pressure arch is developed from the redistribution of the vertical stresses upon development of the roadway. The strata within this pressure arch must be carried by the support system. In the worst case, it will be assumed that the full weight of this strata must be supported as in a detached block concept. In the primitive sense, this can be considered the load-dependent portion of the loading cycle since the support system can be designed to have sufficient capacity to establish complete equilibrium of this rock mass. In reality, the notion that the immediate roof is fully stress relieved and is acting as a detached block is more extreme than what is likely occurring. While the strata is softened, it is still acting as a laminated and perhaps disjointed mass that is still subject to the influence of both vertical and horizontal stress. Observations of compressional failures of the immediate roof, i.e., shortening of the roof, give credence to the fact that horizontal stress is still affecting this area (figure 4). And the source of the forces causing these deformations occur at both the global (longwall) scale and the local (roadway) scale, suggesting that both load-controlled *and* displacement-controlled behavior is occurring. The most obvious example of displacement-controlled loading is pillar yielding. Pillar yielding, being a function of the overburden and abutment stress, is undoubtedly displacement-controlled loading activity since the roof supports are incapable of stopping it. Floor heave also is likely to have elements of displacement-controlled activity as the overburden forces acting on the pillar are transferred into the floor, again creating both vertical and horizontal stress changes in the immediate floor of the mine entry. Figure 4 shows buckling of strong floor in a western U.S. mine in an area supported by a Can[1] support. This type of failure is likely to induce compression of the standing support; hence it can be considered displacement-controlled loading. If the floor is soft, the support may puncture the floor causing it to move around the support and close the entry without necessarily inducing additional loading on the support. If the support also punctures the roof, then the damaged roof is much more likely to develop into a roof fall than if the loading is more widely distributed.

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[1]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Figure 3. A generalized roof control mechanism defined by movement of ground within the pressure arch surrounding the mine opening. (Courtesy of SCT Operations, Australia).

Figure 4. Compressional failures of mine roof and floor due to horizontal stress.

The Ground Reaction Curve

The classic roof control mechanism described above may be an over simplification of the strata behavior, but regardless of what the exact mechanism is, the loading will manifest itself as closure of the mine opening. Hence, it is possible to determine the degree of control that the roof support system has in controlling the convergence of the mine entry, in this case the longwall tailgate. The most accurate way to determine this is by making in-mine measurements of the ground movement and associated support loading. Fundamentally, this embodies the measurement of the ground reaction curve (3 and 4). The minimum requirement is to determine the amount of convergence in the mine entry as a function of the support load density, and from this data, develop a ground reaction curve.

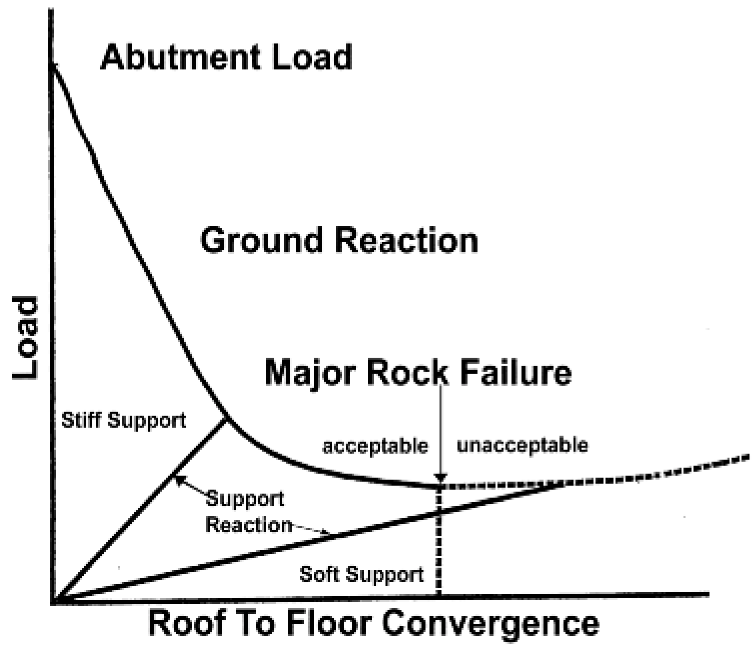

Figure 5. Ground reaction curve concept.

While a ground reaction curve for a longwall tailgate has not been fully and accurately measured, a hypothetical ground reaction curve that is typically used in tunneling (figure 5) will be used to conceptualize the support design issues. This curve shows that the amount of convergence measured in the mine entry will vary depending on how much load resistance is provided by the support system. The support capacity required to achieve equilibrium is reduced as the deformation increases, since the roof is shedding load to other mine structures as it deforms. In other words, by allowing the roof to deform and shed some load to the coal pillars and longwall panel, less support capacity is required since the roof loading is decreased. This trend will occur until a critical deformation is reached which breaches the structural integrity of the immediate mine roof and floor. Hence, the lowest required support capacity would be one that is developed just before this critical roof deformation occurs where failure of the immediate roof is fast approaching. However, designing to this lower limit of support capacity leaves no margin of error in the event that load conditions worsen. If the deformation is allowed to continue beyond this critical level, damage to the immediate roof beam becomes more severe and separations may occur above the bolted horizon requiring the standing support to carry more of the dead weight of the roof rock.

The ground reaction curve also shows that if the convergence is to be eliminated altogether, then the support system must fully offset the abutment loading, which of course is impossible for a secondary support system. Hence, one way to view the ground reaction curve would be to assume that the initial steepest part of the curve represents the displacement-controlled strata behavior since the man-made support systems cannot develop the capacity necessary to eliminate or reduce this level of convergence. The remaining section of the ground reaction curve is the load-dependent section within the realm of available man-made roof support capacities (see figure 6). In essence, only the bottom section of the ground reaction curve is what we are dealing with in the design of man-made standing roof supports. Following this idea then as the abutment loading increases, additional support resistance would be needed to offset this additional loading. As shown in figure 7, this essentially moves the ground reaction curve to the right, thereby increasing the uncontrolled convergence that will occur. As an example, all things being equal, as the depth of cover increases, pillar loading will increase resulting in additional pillar yielding which will produce more uncontrolled convergence. Likewise, if the pillar dimensions were reduced, additional pillar yielding resulting in uncontrolled convergence of the tailgate would also occur. Hence, the amount of uncontrolled convergence is dependent primarily on the global stress behavior of the main roof and overburden rock masses, the pillar design, and to some extent the geology of the mine floor since it may be squeezed into the mine opening in the form of floor heave.

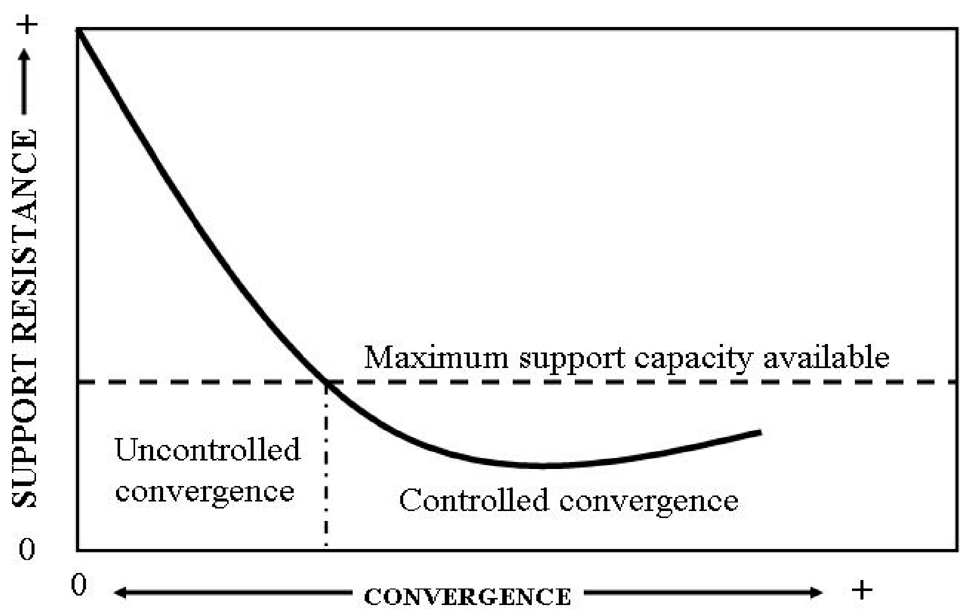

Figure 6. Man-made supports are incapable of providing sufficient load capacity to eliminate all convergence. Hence, there will be a degree of uncontrolled convergence in all longwall tailgates.

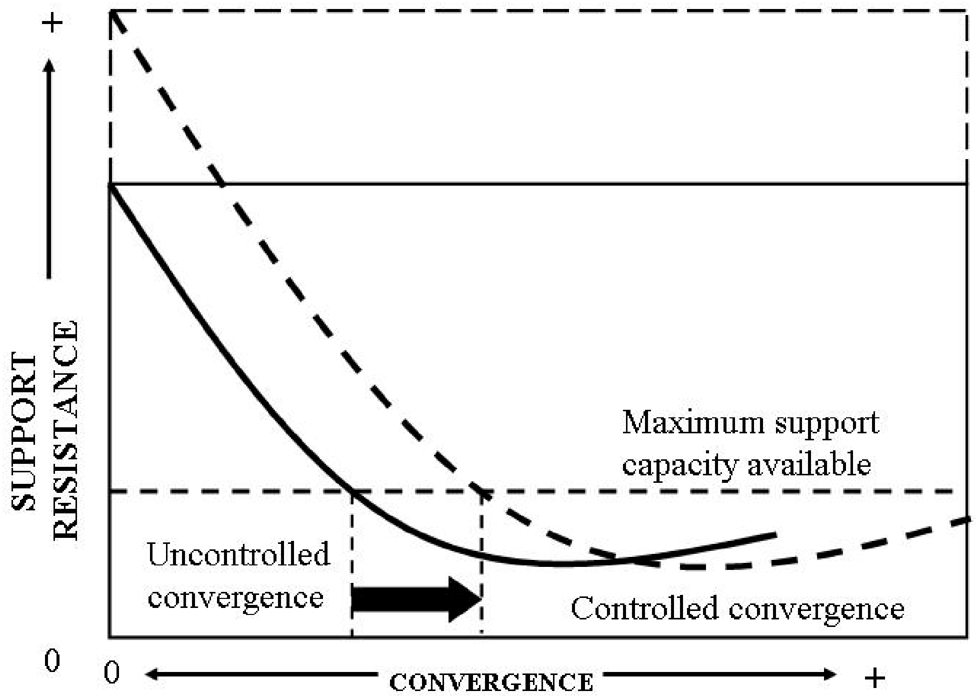

Figure 7. As the stresses increase due to factors such as the depth of cover, then higher loads are needed to offset the increase in stress which expands the magnitude of the uncontrolled convergence and in essence pushes the ground reaction curve to the right.

In summary, the ground reaction curve is a useful concept to visualize the support and strata interactions that are relevant to standing roof support design. As discussed, both displacement-controlled and load-controlled strata activity is undoubtedly occurring in all longwall mining. The next section will discuss the implications of this loading behavior on the support design requirements.

Support Design Requirements

Since the loading environment in all longwall gateroads is a combination of displacement-controlled and load-controlled strata activity, then it is important to understand the impact and difference between the two. If the loading was completely displacement-controlled, the support can be considered as a passenger to the closure of the entry in that the deformation cannot be stopped by the support system, and the support system would simply be compressed by the closure of the opening. If there were no decoupling of the strata layers or creation of isolated rock sections, then there essentially would be no benefit to having a standing roof support system. It can be argued that a standing roof support system would, if anything, do more harm than good since it may puncture into the roof and floor and cause further instability of the rock mass. This would suggest that in a displacement-controlled load environment, a soft support system would perform better than a stiff support system, particularly if the stiff support sheds load after reaching its peak capacity. Hence, for displacement-controlled loading, the primary support design requirements are to ensure that the support will survive the uncontrollable convergence, and be able to sustain its load-carrying capacity throughout this period, and to ensure that the bearing area of the support is sufficient to distribute the stress generated from the support loading to the mine roof and floor without causing further damage to it.

On the other hand, if the environment was completely load-controlled, the most critical design parameter would be the stiffness of the support since a passive standing support requires convergence of the mine roof and floor in order for the support to develop its load carrying capacity and function as a roof support. Typically stiff support systems would be preferred in a load-controlled environment to minimize the deformation of the immediate roof. If the support is too soft, too much deformation will occur causing failure of the mine roof (see figure 5).

Hence, when both load-controlled and displacement-controlled behavior occurs, there are conflicting design requirements and compromises must be made to achieve the optimum support design. Depending on the amount and timing of the displacement-controlled loading, the same support system may work fine in one application and fail in another. Displacement-controlled loading or uncontrolled convergence can make soft supports perform well in areas where stiff supports fail, while stiff supports will provide superior roof control in a load-controlled environment. A prime example of this is the 3C support[1], which is the predecessor to the modern Can support. The load-displacement curve for the 3C support is shown in figure 8. As seen from this graph, this particular support requires over a foot of convergence to provide a useful capacity for support of the mine roof. Yet the support was successfully used in a longwall tailgate in a deep cover mine in the Western U.S. The reason it performed adequately was that the mine employed a yielding pillar design, in which pillar yielding and floor heave occurred during first panel mining that compresses the support (figure 9) and mobilizes a stiffer support response for second panel mining in the active longwall tailgate. This concept can be illustrated on the ground reaction curve (figure 10). Shown is the load-dependent portion of two hypothetical ground reaction curves, the first one with little displacement-controlled activity and the second one with much more displacement-controlled loading that shifted the curve to the right as previously described. As seen in the figure, the 3C support is much too soft to generate sufficient loading to achieve roof control in the first ground reaction curve, but does provide the necessary capacity when the uncontrolled convergence is large. In comparison, the Can support would perform well in both these environments, as it develops its load carrying capacity relatively quickly and is able to sustain this load carrying capacity through a large displacement range (see figure 10). Conversely, concrete donut cribs and Magnum concrete supports, which have very high load carrying capacities, but are very stiff supports (figure 11), have failed prematurely in many western mines operating in similar conditions to the 3C support and yet have performed satisfactorily in some eastern mines. Again, different degrees of displacement-controlled loading were most likely the reason why successes turned to failures in the application of the same support technology.

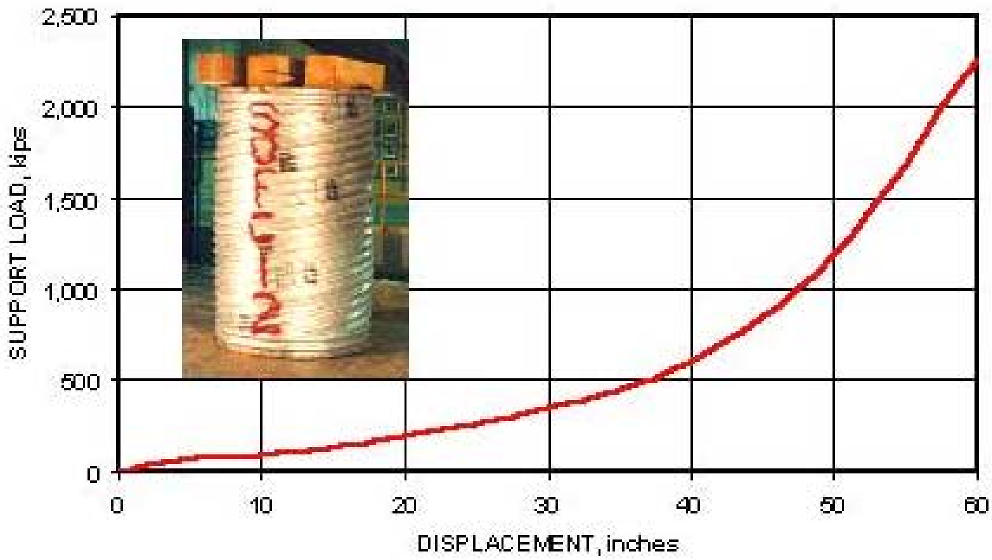

Figure 8. Loading profile for the 3C support illustrating a soft response requiring considerable convergence to produce useful roof support capacity.

Figure 9. Large amounts of floor heaver shown outby the longwall face caused compression of the support which allowed it to develop sufficient load-carrying capacity for roof support in this installation.

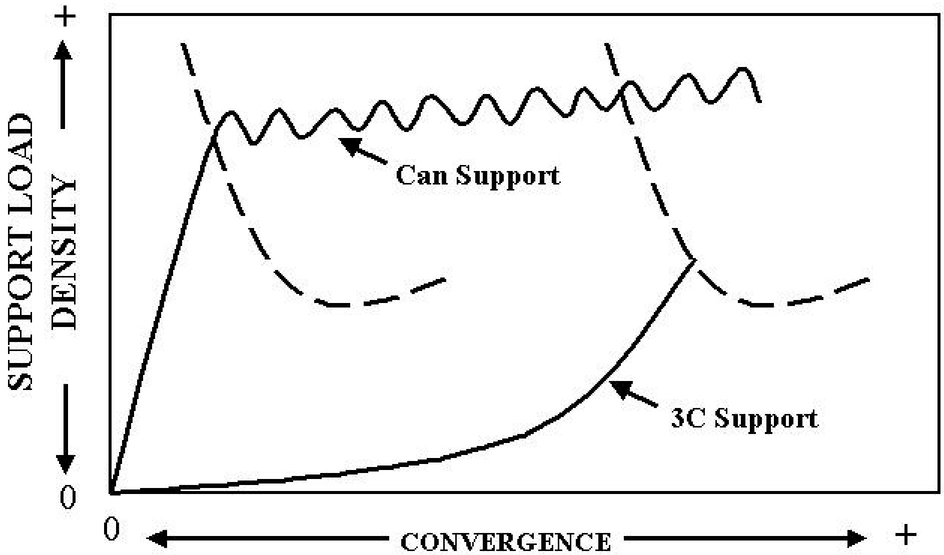

Figure 10. The Can support performs well in both load-controlled and displacement–controlled environment while the 3C support fails to provide roof control in the absence of the uncontrolled convergence.

Figure 11. Failure of stiff concrete supports in a displacement–controlled environment.

In summary, standing roof support systems are installed to control the immediate roof of the longwall tailgate, and are designed to have sufficient capacity to support the full weight of the unstable rock within the pressure arch developed in the mine roof. Being able to reduce the deformations of the immediate roof to prevent further damage that can lead to a roof fall with a passive roof support structure requires a stiff support design. However, the immediate roof and the coal pillars are undoubtedly also subjected to tremendous ground forces that produce closure of the longwall tailgate. Trying to resist all of this closure with any standing roof support system is futile, but must be considered in the support design since it will produce loading in the support structure and associated reactive forces on the mine roof and floor. The ideal support would ignore the displacement-controlled loading, but since that is not possible, tradeoffs must be made to provide an optimized support design. The first requirement is that the support must be able to survive the uncontrolled portion of the convergence without failing and ideally without shedding load. Stiff supports that reach their peak load with little displacement and then lose their load carrying capacity especially dramatically or near fully will not function well in a highly displacement-controlled load environment. In addition, the timing and consequences of the support loading from the displacement-controlled strata activity must also be considered. Trying to resist uncontrollable convergence can be detrimental to providing control of the roof if the reaction forces become large enough to damage the immediate roof or floor. For displacement-controlled loading, the limiting factor may not be whether the support can generate enough loading, but whether it generates too much loading. Hence the bearing area of the support relative to the strength of the immediate roof and floor is a critical design parameter, particularly for stiff roof support systems which are likely to develop significantly loading with very little convergence.

Using the NIOSH Stop Program To Help To Determine Ground Reaction Behavior And Evaluation Of Various Support Applications

The Support Technology Optimization Program (STOP) was developed by NIOSH to assist mine operators, MSHA inspectors and other regulatory personnel in evaluation of the numerous support products that are now available for underground mining (5). One of the support design criteria options included in the program is the Ground Reaction Curve. The program allows you to develop a ground reaction curve and then use it as the basis for the support design or for evaluating alternative support designs.

The first point to understand in generating a ground reaction curve is that it requires data from different support systems or different arrangements of the same support system. A single support application provides one data point on the ground reaction curve not the full curve. The most difficult part of obtaining data points to generate a ground reaction curve is to measure the support loading. This can be done directly, typically with some sort of hydraulic load cell. NIOSH recently utilized a cell typically used for prestressing supports as a load cell to measure the load development on pumpable roof supports at a western PA mine (see figure 12). This cell is currently produced in South Africa and is being marketed by Heintzmann Corporation[1] in Cedar Bluff, VA. It can be formed in nearly any shape, and therefore can be used to measure load development on many different support products. Convergence measurements can be taken with wire-pull displacement transducers or simply directly measured, and recorded provided a consistent reference point or anchor is maintained.

Figure 12. Hydraulic cell used to measure loading on a pumpable roof support in a longwall tailgate.

This data can be entered into the STOP program and a ground reaction curve can be generated. STOP also will compute the support loading from its database of loading characteristics (load-displacement data) of the various support systems if convergence measurements are made (see figure 13). Since measurement of the support loading is the most difficult part, this can be very helpful in obtaining the necessary information for developing the ground reaction curve. Once the ground reaction curve is developed, a support application can be designed that will function in this environment and provide the desired level of convergence control, thereby optimizing the support design.

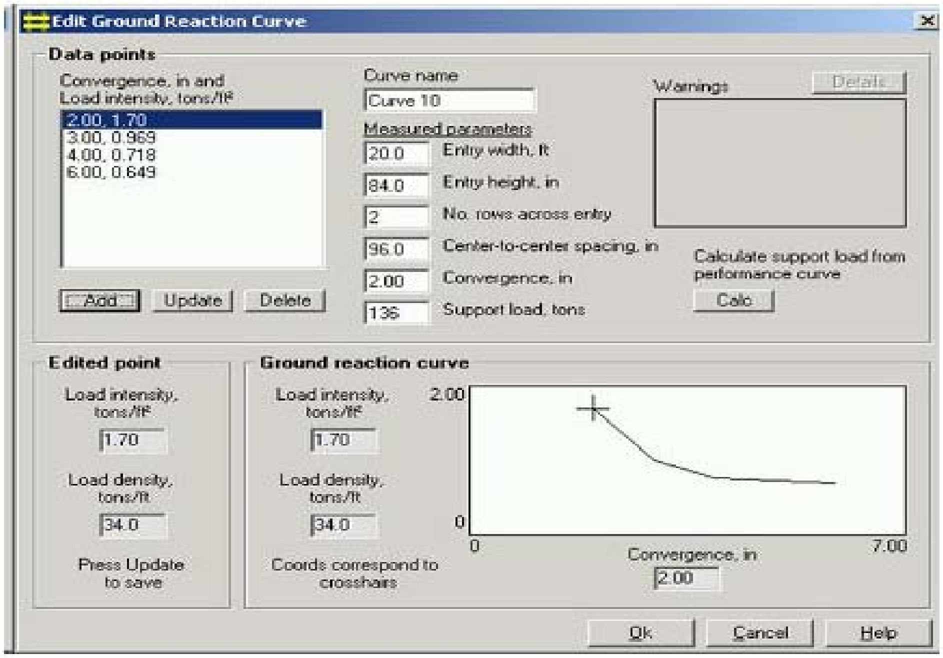

Figure 13. Use of the NIOSH STOP software to develop a ground reaction curve.

Another way to handle displacement-loading behavior in the STOP is to input an uncontrolled convergence as part of the design criteria, which can be done in any of the design criteria options. The timing of the uncontrolled convergence is also part of the design consideration. Two options are available: (1) *Independent* or (2) *Concurrent*. When the independent option is selected, the design convergence is set to the controlled component of the convergence, and a security check is made to see if the support can maintain the required capacity through the total convergence, which is the sum of the controlled and uncontrolled component. If the support cannot maintain the capacity through this range of convergence, a warning is issued in the *Warnings box*. Essentially, this option is saying that timing of the uncontrolled convergence is such that it should not be relied upon to generate the required capacity of the passive roof support system to maintain roof control, however, the support must be stable enough to continue providing this necessary capacity to control the roof deformation should floor heave, pillar yielding, or any other uncontrolled convergence occur.

The following is an example of using independent, uncontrolled convergence in an evaluation of standing roof support design. A 100-ton Heintzmann ACS support[1] is selected for this analysis. The design criteria were chosen based on the performance of a conventional 4-point wood crib support system, which has previously been successfully utilized in this situation. Using the current support system to establish the design criteria (figure 14), a load density of 11.6 tons/ft at 3 inches of convergence was established for a double row of 4-point cribs constructed from 6x6x36-in poplar timbers on a 96-inch spacing. It is also shown that an uncontrolled convergence of 5 inches is set. As seen in the design criteria summary at the bottom of the form, the uncontrolled convergence timing is designated as *Independent* and a *security check* is set up at 8 inches of convergence equating to the sum of the controlled (3 inches) and uncontrolled convergence (5 inches). Figure 15 depicts the performance window for the ACS support. It is seen that the required spacing of a single row of ACS props to provide the required 11.6 tons/ft at the design convergence of 3.0 inches is 77.1 inches. However, as the *Warnings box* shows, the ACS support is in yield at 3 inches of convergence and fails to provide the required 11.6 tons/ft at 8.0 inches when the uncontrolled convergence is added to controlled component. It is seen from the *Ground Behavior and Support Performance box* that the ACS reaches its peak loading at about 2.25 inches and sheds loads fairly quickly after reaching its peak load.

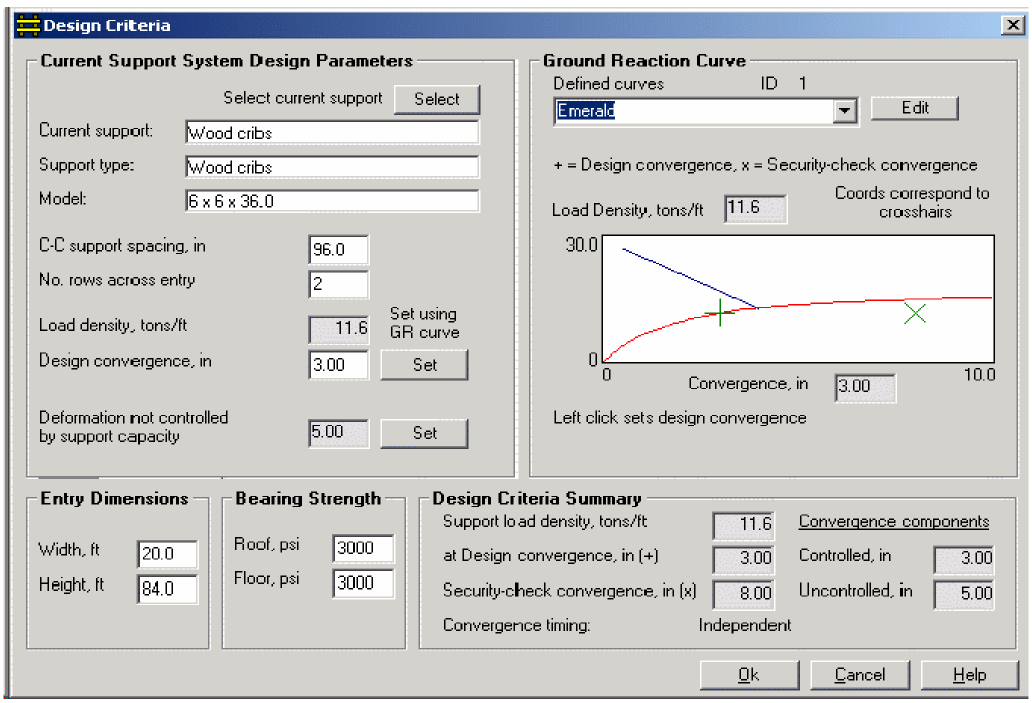

Figure 14. Design criteria based on the performance of a 4-point wood crib with an uncontrolled convergence of 5 inches included with a design convergence of 3 inches.

The other option is for the designation of the timing of the uncontrolled convergence to be *Concurrent*. This means that it is occurring at the same time as the controlled component of the convergence and is thus acting to mobilize the support capacity to provide roof control. The design convergence for the support analysis is then set to the sum of the controlled convergence and the uncontrolled convergence. In this case, the security check is set at the controlled component of the convergence. The idea is to check to see that if the uncontrolled convergence did not occur, would the support have the same or greater capacity as it would with the uncontrolled convergence. The previous example of the 4-point wood crib support system as the current support system is again used, except now the timing of the uncontrolled convergence will be designated as *concurrent* and the design convergence will include the 5 inches of uncontrolled convergence. As seen in figure 16, the load density requirement at 8 inches of convergence for the wood crib support system on a 96-in spacing is 14.9 tons/ft. Figures 17 and 18 depict the assessment of the current 4-point wood crib (figure 17) and a Propsetter support[1] (figure 18). The wood crib system continues to provide greater support capacity as the convergence continues (see the performance curve in the *Ground Behavior and Support Performance box*). Hence, if the uncontrolled convergence did not occur, the wood crib system at the 96-in spacing would not provide 14.9 tons/ft at 3 inches of convergence, and hence, the wood crib support system fails the security check. The Propsetter support on the other hand, reaches its peak loading early in the loading cycle, and although the support is yielding at 8 inches of convergence, it provides the required support capacity at 3 inches of convergence as well.

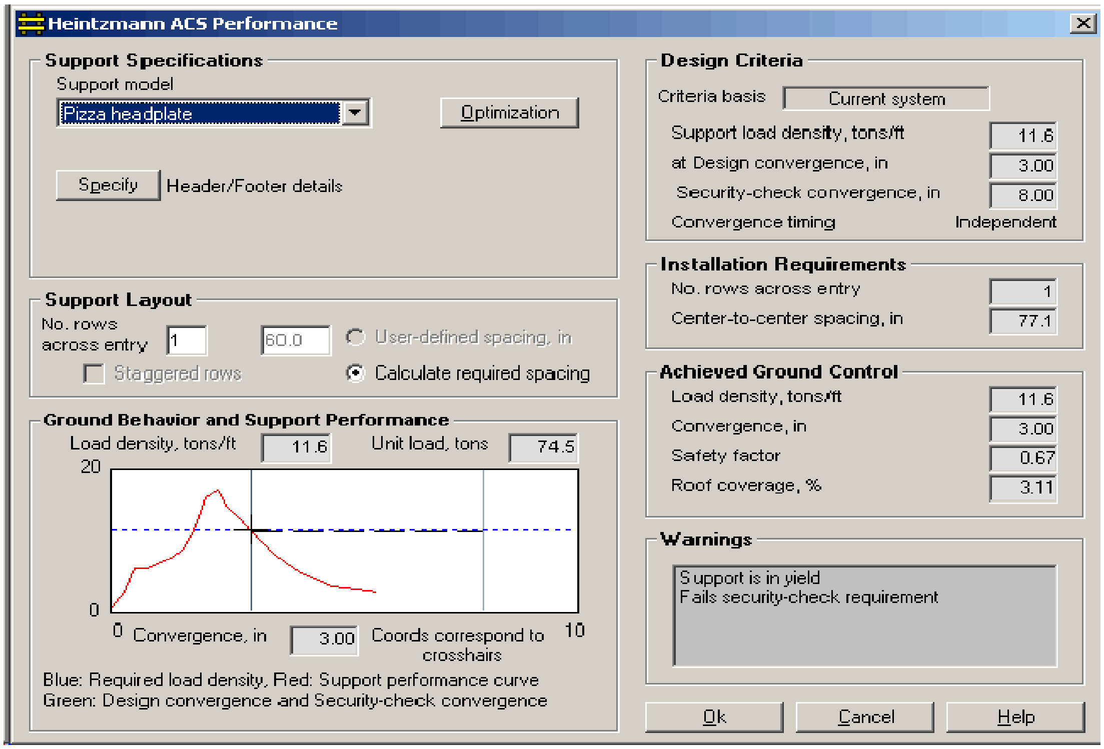

Figure 15. Performance window for ACS support showing that the support cannot provide the required loading at 8 inches of convergence.

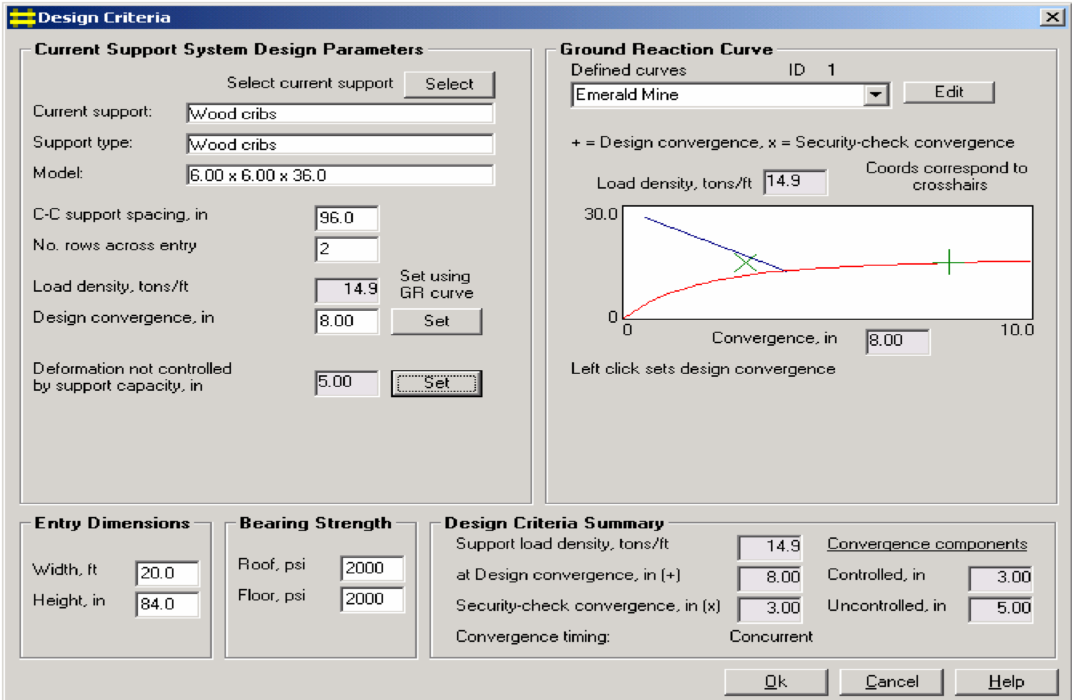

Figure 16. Design requirements set at 14.9 tons/ft with at a design convergence of 8 inches including 5 inches of uncontrolled (concurrent) convergence.

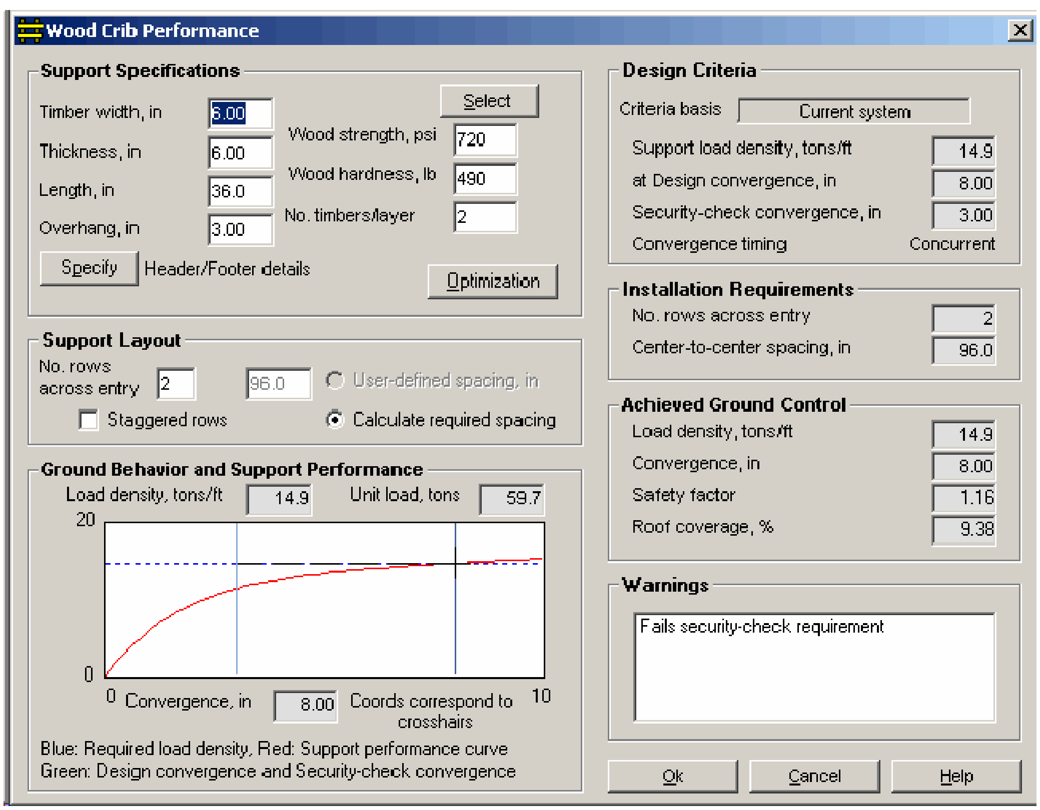

Figure 17. A conventional 4-point wood crib fails to provide the required 14.9 tons/ft at 3 inches of convergence.

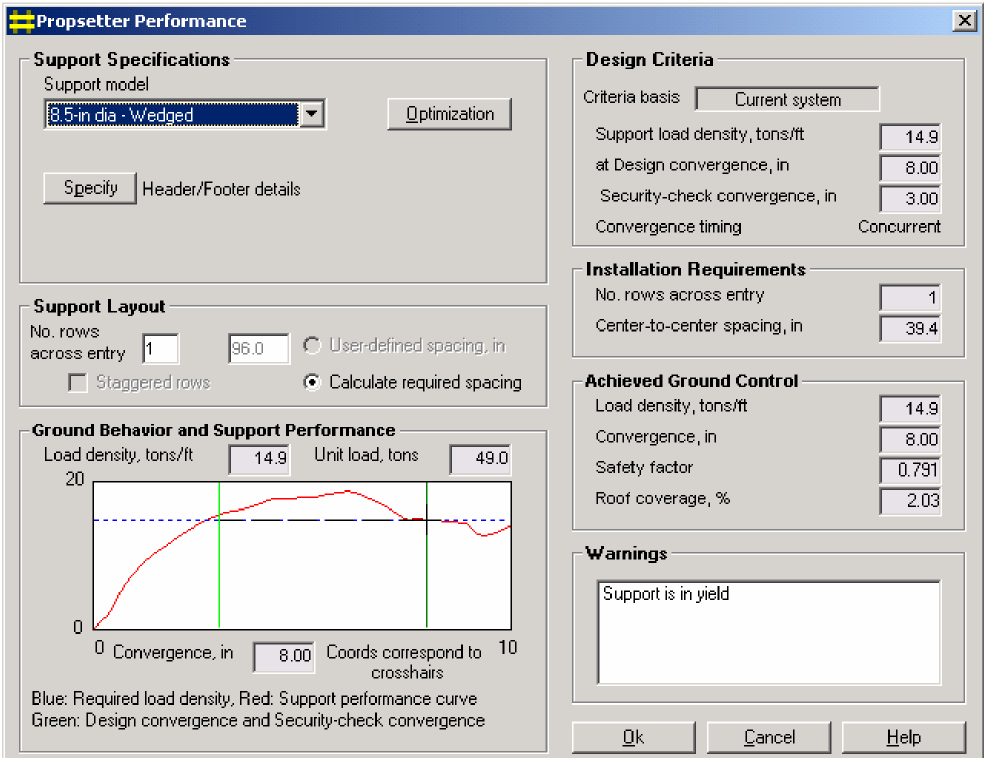

Figure 18. The Propsetter support on the other hand can provide the required 14.9 tons/ft at both 3 and 8 inches of convergence.

The Ideal Support – Is There One?

So how would the ideal standing roof support behave assuming both load-controlled and displacement-controlled loading is occurring? The ideal support would ignore displacement-controlled loading (have no stiffness) to avoid developing unnecessary support loading and stressing of the mine roof and floor, and then be very stiff in the presence of load-controlled strata activity to minimize the deformations of the immediate roof. Obviously, such a "smart" support system that can distinguish between displacement-controlled and load-controlled strata behavior does not exist. A more realistic ideal support would be one that: (1) can provide an adjustable, active load to the mine roof and floor, (2) is stiff initially to assist in load-controlled roof activity, (3) can provide a designated and preferably an adjustable peak load, (4) is able to sustain the designed peak load over a designated range of vertical displacement, (5) can adequately distribute the loading to the mine roof and floor, and (6) can remain stable against relative horizontal movement of the roof and floor. About the only current support technology that provides this degree of design flexibility is a longwall shield. While shields provide effective ground control in the face area, they are not a practical solution for tailgate support. Since tailgate supports are also abandoned, a hydraulic jack which is capable of fulfilling the design criteria described above is also not a cost effective solution. Hence, the traditional longwall tailgate supports have relied on the deformation properties of the construction materials themselves to control the load response.

Wood has been the traditional support construction material, but wood suffers from being too soft (when loaded perpendicular to the grain) or unable to yield sufficiently (when loaded parallel to the grain). To resolve these deficiencies, engineered timber support systems such as the Hercules, Link-N-Lock, and Tri-log crib and the Propsetter support have improved the performance of crib and post type timber supports for use in longwall tailgates[1]. In the crib type supports, there is a fairly wide range of capacities that can be designed and the initial stiffness is improved over that of conventional cribbing. There is some loss of yield capability as the products become stiffer, but not to the extent that it significantly limits the application of these products. The Propsetter extends the yield capability of conventional timber posts to 6-10 inches of effective yield capability. The Propsetter also provides an option for prestressing using a special headboard and pressurized grout bag at the roof interface. Figure 19 illustrates the load-displacement behavior for samples of these engineered timber supports.

The Can support[1], which is heavily used in western mines as well as in many eastern mines with moderate seam heights, probably comes closest to achieving the overall performance design objectives of the ideal support. The Can utilizes a weak cellular (air entrained) concrete material inside a thin-walled steel container. The weak cementitious material crushes into the voids in the material and the steel container confines the crushed material much like a hydraulic cylinder confines the water or oil inside it. The capacity and stiffness of the support can be controlled by changing the diameter of the support. Figure 20 illustrates the load-displacement behavior for the Can. While the Can support performance can be considered ideal, the system requires considerable logistics to transport these prefabricated units into the mine, and requires specialized equipment to pick the units up and place them in the mine entry. They must also be topped off with wood timbers to establish roof contact, which can degrade the performance of the support by softening it or reducing the stability of the structure if not done properly.

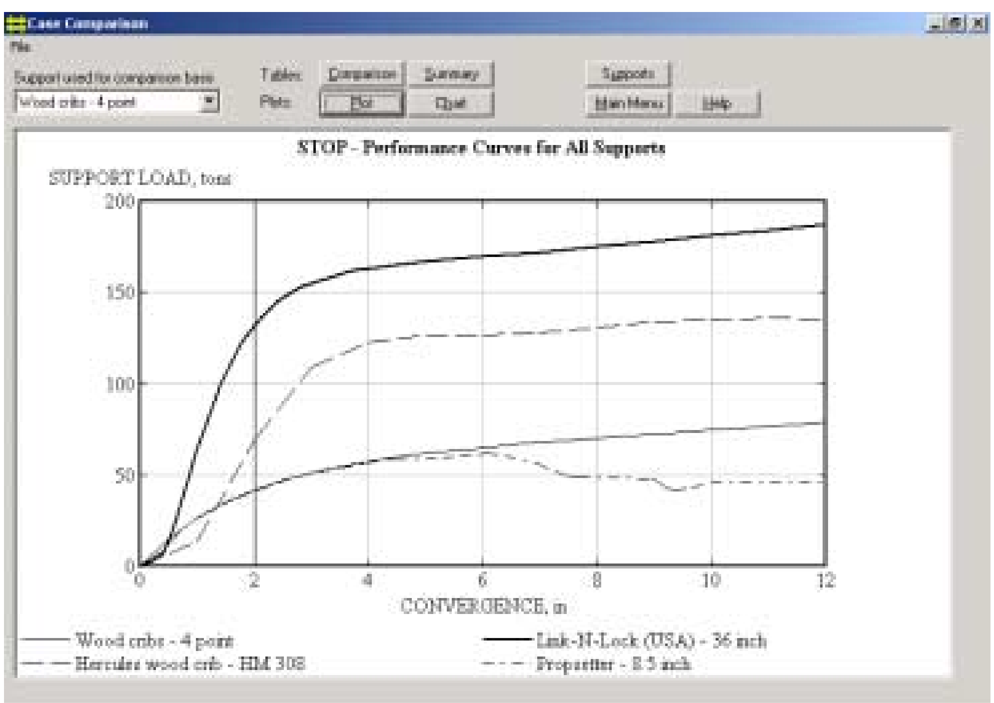

Figure 19. Load profile of some engineered timber support products in comparison to conventional 4-point wood cribbing.

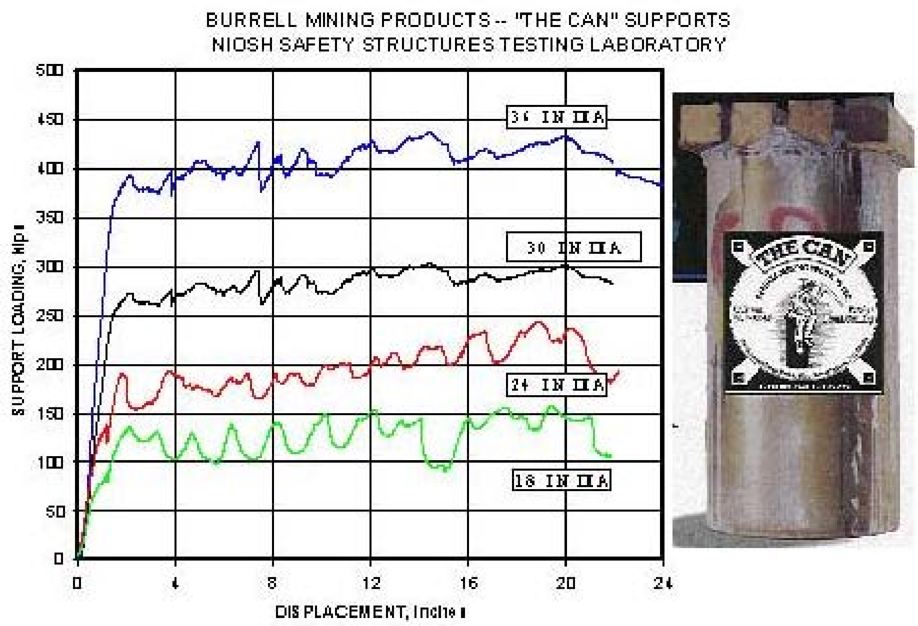

Figure 20. Load profile for Can supports.

Latest Developments in Standing Roof Supports for Longwall Tailgates

Pumpable roof support technologies were developed to compete with the Can support and overcome some of its deficiencies. Unlike the Can support, these supports are filled in place in the mine entry, and in so doing, eliminate the safety concerns and material handling constraints associated with the Can support. They also eliminate the need for a secondary material to establish roof contact. The pumpable supports easily conform to the mine roof and floor providing a stiffer and more uniform initial response than Can supports with wood topping material.

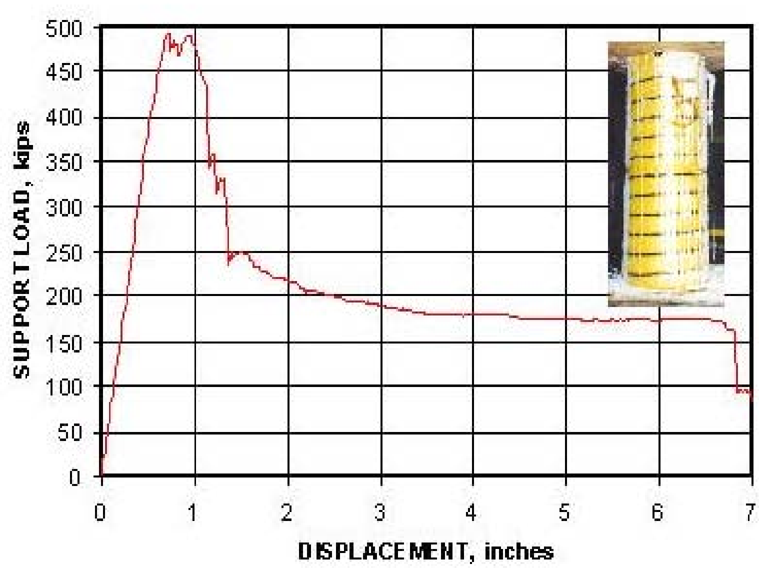

Figure 21. Loading profile for a pumpable roof support (Heitech–30-in diameter).

Currently, pumpable roof supports are constructed in bags that are 2.0-2.5 feet in diameter which are hung from the mine roof and pumped full of some form of cementitious material. HeiTech, an affiliate of Heintzmann Corporation, has the most experience in the USA with this support technology, and has been installing pumpable roof supports at two mines in western PA for the past 4 years. The HeiTech system utilizes a calcium sulfo-aluminate (CSA) based, two-component grout that has successfully been pumped distances of 15,000+ feet from a surface borehole to underground locations within the longwall tailgate and bleeder entries. A performance curve for a representative, 30-inch diameter, HeiTech pumpable support is shown in figure 21. As seen from graph, the support exhibits a stiff initial response reaching a peak load of 250 tons in less than 1 inch of convergence. When the peak load is reached, the brittle grout material in the bag fractures, resulting in significant load shedding. The residual capacity of about 180 kips (90 tons) is dependent upon the bag to confine the fractured grout. The profile of this support suggests that it would perform well in a load-controlled environment, but not as well in a displacement-controlled environment where it is pushed beyond its peak capacity. The photo shown as figure 22, depicts this support in a longwall tailgate just inby the face where the loading should be at its maximum. It is observed that the bag is not noticeably deformed and apparently has not been loaded beyond its peak capacity. This suggests that in this particular application, this is primarily a load-controlled environment or that the displacement-controlled loading produced less than 1 inch of convergence. A current study is underway to measure the ground reaction behavior at this particular mine site, which should provide more information on the nature of the loading behavior as the support spacing and grout strength is varied in the test areas.

Figure 22. Pumpable support just inby the face showing that the support has not deformed much, indicating that this is primarily a load-controlled environment or that the displacement-controlled activity did not cause more than 1 inch of convergence.

Another trend in longwall tailgates is the upgrading of yieldable prop supports for application in longwall tailgates. A good example of this is the Rocprop (figure 23). The Rocprop consists of two telescoping metal tubes with a wedge-shaped collar that is forced downward inside the bottom tube, causing deformation of the steel which provides controlled yielding through a large displacement range (figure 23). The capacity of the support, which traditionally had been used in longwall recovery operations and as supplemental support, has recently been upgraded from 25 to 50 tons.

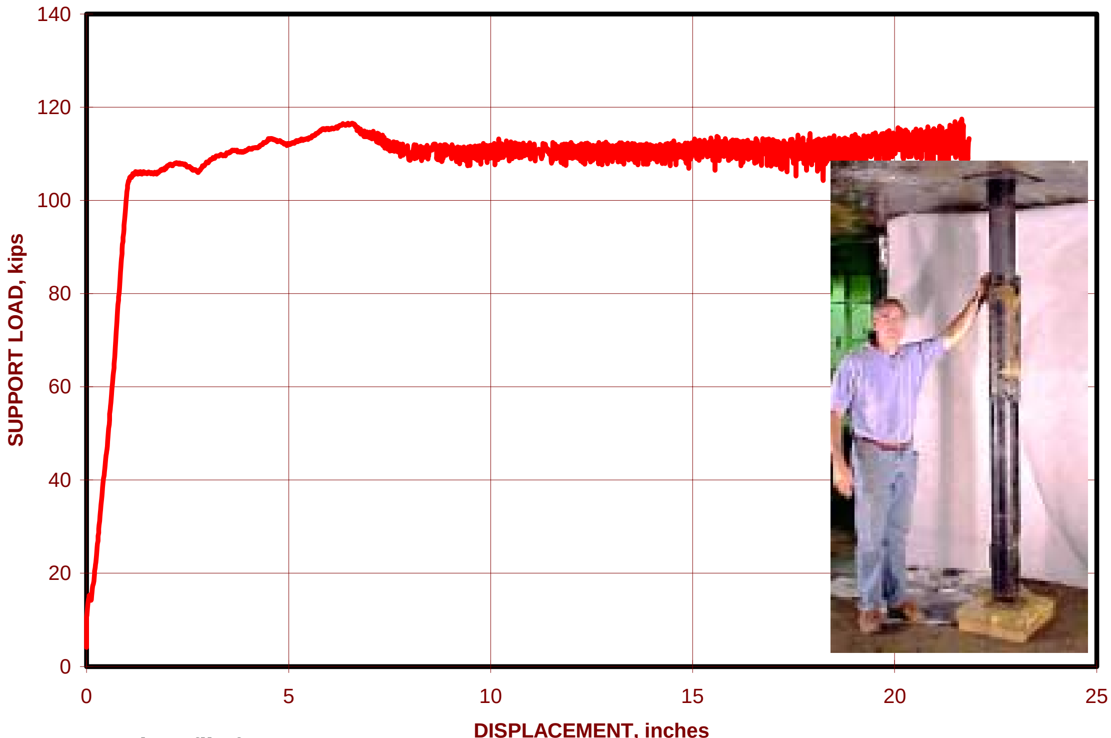

Figure 23. Load profile for a 50 ton Reoprop support.

Other Considerations In Support Optimization

Thus far, this paper has focused on matching the loading characteristics of the support to the ground activity to optimize the performance of the support system. In addition to this primary design requirement, several other factors may influence the roof support selection, which may then also have an impact on the optimization process. Material handling is an ever-increasing factor in support selection, and for good reason, since most injuries are associated with the construction of the support and not falls of ground. A complete assessment of material handling requirements is considered beyond the scope of this paper, but there are valuable references which detail the material handling aspects of most modern standing support systems (6). One reason for the popularity of the Can support, in addition to its superior loading characteristics, is that it can be installed with a machine and thereby eliminate most of the physical work required to install the support. Yet, in some mines, transporting the bulky Can supports into the mine can be problematic as previously indicated. Again, this indicates that even in terms of material handling, some supports will be preferred in one application and not in another. The NIOSH STOP program can also be used to evaluate both the material handling and cost parameters associated with a particular support system.

SUMMARY AND DISCUSSION

Today, there is a variety of standing roof support products available for use in longwall tailgate applications. Each support has a unique loading profile. While many of these supports can provide adequate ground control in a variety loading conditions, some will perform better than others in certain circumstances. The goal to selecting the most appropriate support and optimizing its use is to match the behavior of the support to the ground conditions in which it is employed. The paper describes the use of the ground reaction curve as a means to evaluate the effectiveness of a support application in controlling the movement of the ground. By developing a ground reaction curve for a particular longwall tailgate, the required support load density necessary to provide the desired degree of convergence control can be ascertained. Once this is done, the required spacing of a particular support system necessary to achieve this degree of convergence control can be determined, and the application of this particular support system can be optimized based on these (convergence control) criteria.

It is proposed that the loading environment in longwall mining is composed of a combination of load-controlled and displacement-controlled strata activity. By definition, displacement-controlled activity results in convergence (displacement) of the mine roof and floor in the tailgate entry that cannot be controlled by the capacity of the support system. In essence, the support system is simply going along for the ride, having no effect on the ground movement. However, the softened ground within the immediate roof must still be supported in order for it to remain in a stable configuration while the uncontrolled convergence of the entry is occurring. Hence, the standing support must be able to sustain its load-carrying capacity while it is being deformed (squeezed) from the uncontrollable convergence associated with the global ground activity. It is also necessary to understand how the support system changes its loading characteristics as it goes through its loading profile. If the support is initially stiff, but sheds load as the convergence increases, then this type of support will not perform as well in a displacement-controlled environment as one, which maintains or slowly increases its load-carrying capacity as the convergence continues. Hence, a key ingredient to selecting the most appropriate support and optimizing its use is to determine the degree and timing of the displacement-controlled loading activity that is occurring. It is also proposed in the paper that this can be accomplished through the measurement of the ground reaction curve, whereby the ground reaction curve would shift to the right as the uncontrolled convergence increases.

NIOSH developed the Support Technology Optimization Program (STOP) as a tool to facilitate in the optimization of tailgate support selection and utilization. STOP can be used to obtain ground reaction data and develop design criteria for standing roof supports using the ground reaction curve developed from this data. The program can then be used to evaluate different support products and optimize their use based on the ground reaction criteria for a particular longwall tailgate.

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